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INVESTIGATION OF THE ATMOSPHERE BY RADIOASTRONOMICAL METHODS AT SMALL ANGLES ABOVE THE HORIZON

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SUMMARY

Theoretical and experimental investigations of atmosphere's radioemission temperature have been conducted in the decimeter band for angles from 0°30' to 10°. Effective lengths are found for the absorption coefficient. Measurements of refraction attenuation of antenna amplification were also conducted. It was found that the latter takes place for angles <2.5° above horizon, and increases as the altitude decreases. Thus, for an antenna with half-power level pattern near 40' at heights 0°30' the amplification drops by 60%. It was shown also that at refraction attenuation of the amplification the antenna scattering remains the same as for a uniform medium.

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The influence of the atmosphere on the reception of sources located beyond its limits is especially material at small angles (<5°) to the horizon, and is manifest in such phenomena as refraction, absorption and refraction attenuation. At present only radiowave refraction is studied theoretically and experimentally with sufficient detail, while experimental data on the attenuation of the intensity of signals, having crossed the atmosphere at small angles, is entirely absent.

The theoretical estimates of absorption also require revision [1, 2], inasmuch as they were based on experimental data, later made substantially more precise.

The present work deals with the results of experimental investigation of atmosphere's radioemission temperature, of radiowave absorption and of refraction attenuation of antenna amplification, performed at small angles to the horizon, using radioastronomical methods over the wavelength $\lambda = 30$ cm. Inasmuch as the absorption coefficients in oxygen and the refraction index in water vapor and oxygen do not vary in centimeter and decimeter bands, the results obtained are valid for all wavelengths of these bands.

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* ISSLEDOVANIYE ATMOSFERY NA MALYKH UGLAKH NAD GORIZONTOM RADIOASTRNOMICHESKIMI METODAMI.

Taking into account the refraction, the radioemission temperature of the atmosphere in a given direction is determined quite well by the known expression

$$T_a = \int_0^\infty \varkappa(h)\, T(h)\, e^{-\int_0^l \varkappa(h)\, dl}\, dl, \qquad (1)$$

where $\kappa(h)$ is the absorption coefficient of radiowaves in the atmosphere; T(h) is the kinetic temperature; dl is an element of path. In the case of spherically stratified atmosphere the latter is [1]

$$dl = \frac{dh}{\sqrt{1-[n(0)r_0/n(h)r]^2 \sin^2 \theta}} \qquad (2)$$

where n is the index of refraction, r is the radius from the center of the Earth to the considered element dl; θ is the zenithal angle at which the element dl is visible from the point of observation.

If we represent the absorption coefficient in the form $\varkappa(h) = \varkappa_0 e^{-h/H}$, we have

$$l_{\text{эф}} = \int_0^\infty e^{-h/H} dl \qquad (3)$$

which will have the sense of effective wave in uniform atmosphere, which the ray has to cross in such a fashion that the damping be the same as for an infinite nonuniform atmosphere. Then, we shall have for the temperature of atmosphere's radioemission

$$T_a(\theta) = \overline{T(h)}\,(1 - e^{-\varkappa_0 l_{\text{эф}}(\theta)}). \qquad (4)$$

The effective lengths, computed in kilometers with the aid of a computer for the values of absolute moisture 0, 10 and 20 g/cm^3 and temperature interval on the ground from 260 to 300°K, are compiled in Table 1. These effective lengths correspond to waves of the decimeter and centimeter bands, when the absorption takes place only in the molecular oxygen and has a nonresonance character. The value of the effective height for this case was determined experimentally and found to be H = 4 km; the value of the absorption coefficient at sea level is κ_0 = 0.0145 db/km [3].

For waves of the microwave band, corresponding to resonance absorption in molecular oxygen lines, H = 5 km, and the effective lengths are compiled in Table 2.

The mean values of the altitude distribution of kinetic temperature as a function of total absorption in the visual ray and the given direction, which enter in (4), are computed in [4] and are plotted in Figure 1, where the upper curve corresponds to nonresonance absorption, and the lower one — to resonance absorption. For the decimeter band, of interest to us, we may obtain the

TABLE 1

EFFECTIVE LENGTHS IN KILOMETERS FOR THE VALUES OF ABSOLUTE MOISTURE 0. 10 AND 20 g/cm³ AND 260 - 300°K TEMPERATURE INTERVAL ON THE GROUND. DECIMETER AND CENTIMETER WAVES

θ° / T_0,°K	$l_{эф}$ ($e_0 = 0$ г/м³)					$l_{эф}$ ($e_0 = 10$ г/м³)					$l_{эф}$ ($e_0 = 20$ г/м³)				
	300	290	280	270	260	300	290	280	270	260	300	290	280	270	260
80	22,7	22,7	22,7	22,7	22,7	22,7	22,7	22,7	22,7	22,7	22,7	22,7	22,7	22,7	22,7
81	25,0	25,0	25,0	25,0	25,0	25,0	25,0	25,0	25,0	25,0	25,1	25,1	25,1	25,1	25,1
82	28,0	28,0	28,0	28,0	28,0	28,0	28,0	28,0	28,0	28,0	28,1	28,1	28,1	28,1	28,1
83	31,8	31,8	31,8	31,8	31,8	31,8	31,8	31,8	31,8	31,8	31,8	31,9	31,9	31,9	31,9
84	36,6	36,6	36,6	36,6	36,6	36,7	36,7	36,7	36,7	36,7	36,8	36,8	36,8	36,8	36,8
85	43,2	43,2	43,2	43,2	43,2	43,3	43,3	43,3	43,4	43,4	43,4	43,4	43,5	43,5	43,6
86	52,4	52,4	52,5	52,5	52,5	52,6	52,7	52,7	52,7	52,8	52,8	52,9	53,0	53,0	53,1
87	66,2	66,3	66,3	66,4	66,4	66,7	66,8	66,8	66,9	67	67,1	67,2	67,4	67,5	67,6
88	88,6	88,7	88,8	88,9	89,0	89,6	89,8	90,0	90,2	90,4	90,7	91,0	91,3	91,6	91,9
88°30′	106,0	106,1	106,3	106,5	106,6	107,6	107,8	108,1	108,4	108,8	109,2	109,6	110,1	110,5	111,1
89	129,5	129,8	130,0	130,2	130,6	132,4	132,9	133,4	133,9	134,6	135,5	136,2	137,0	137,9	138,9
89°30′	163,8	164,2	164,7	165,2	165,7	169,3	170,5	171,1	172,2	173,4	175,4	176,8	178,4	180,2	182,3
90	199,2	200,0	200,6	201,4	202,3	209,2	210,8	212,5	214,5	216,8	221,1	223,9	227,2	230,9	233,3

TABLE 2

EFFECTIVE LENGTHS IN KILOMETERS FOR THE VALUES OF ABSOLUTE MOISTURE 0, 10 AND 20 g/cm³ AND 260 - 300°K TEMPERATURE INTERVAL ON THE GROUND. MICROWAVES

θ° / T_0,°K	$l_{эф}$ ($e_0 = 0$ г/м³)					$l_{эф}$ ($e_0 = 10$ г/м³)					$l_{эф}$ ($e_0 = 20$ г/м³)				
	300	290	280	270	260	300	290	280	270	260	300	290	280	270	260
80	28,2	28,2	28,2	28,2	28,2	28,2	28,2	28,2	28,2	28,2	28,2	28,2	28,2	28,2	28,2
81	31,2	31,2	31,2	31,2	31,2	31,2	31,2	31,2	31,2	31,2	31,2	31,2	31,2	31,2	31,2
82	34,8	34,8	34,8	34,8	34,8	34,8	34,8	34,9	34,9	34,9	34,9	34,9	34,9	34,9	34,9
83	39,4	39,4	39,4	39,4	39,4	39,4	39,4	39,5	39,5	39,5	39,5	39,5	39,5	39,6	39,6
84	45,3	45,3	45,3	45,3	45,3	45,4	45,4	45,4	45,5	45,5	45,5	45,5	45,5	45,6	45,6
85	53,2	53,2	53,3	53,3	53,3	53,4	53,4	53,4	53,5	53,5	53,5	53,6	53,6	53,7	53,7
86	64,3	64,3	64,4	64,4	64,4	64,6	64,6	64,7	64,7	64,8	64,9	64,9	65,0	64,1	65,2
87	80,6	80,7	80,8	80,8	80,9	81,2	81,3	81,4	81,5	81,6	81,7	81,8	82,0	82,2	82,3
88	106,4	106,5	106,6	106,8	106,9	107,6	107,8	108,1	108,3	108,6	108,9	109,2	109,6	110,0	110,4
88°30′	125,1	125,3	125,5	125,7	125,9	127,1	127,5	127,9	128,3	128,7	129,3	129,8	130,4	131,0	131,8
89	151,7	152,0	152,3	152,6	152,9	155,0	155,5	156,1	156,8	157,5	158,5	159,3	160,3	161,3	162,5
89°30′	188,1	188,6	189,1	189,7	190,3	194,2	195,2	196,3	197,5	198,8	201,0	202,6	204,4	206,4	208,7
90	224,6	225,4	226,2	227,1	299,1	235,4	237,1	239,0	241,2	243,6	248,1	251,2	254,7	258,7	263,5

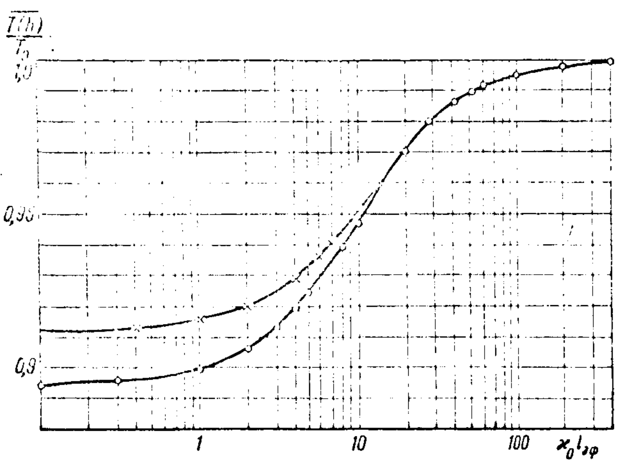

Fig.1

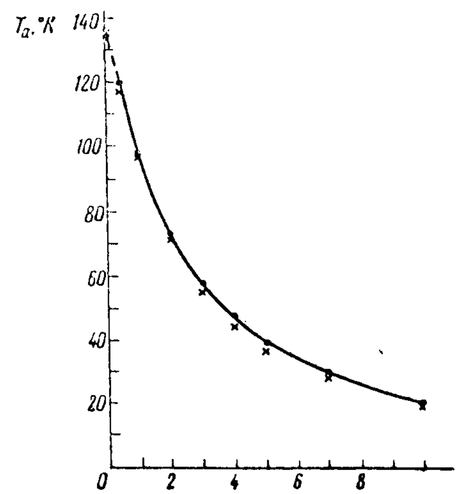

Fig.2

the analytical expression for $\overline{T(h)}$:

$$\overline{T(h)} = T_0 - 6.5H = T_0 - 26^\circ K \tag{5}$$

where it is assumed that the mean gradient of temperature decrease with altitude is 6.5°K/km. The radioemission temperature of the atmosphere is calculated for the conditions, at which measurements were conducted: $T_0 = 290^\circ K$ and $e_0 = 10$ g/m and plotted in Fig.2. It is interesting to note that, though in decimeter wave band the absorption coefficient does not depend on absolute moisture, the atmosphere's radioemission temperature depends on it through the effective path length.

During experimental investigations of thermal radioemission of the atmosphere the vertical distribution of temperatures, received in the solid angle of the main ray of the diagram, is measured with the aid of a radiotelescope. At great altitudes, where the atmosphere refraction can be neglected, the antenna radiation pattern coincides with the pattern in a uniform medium F_0.

Measuring the atmosphere's radioemission with a narrow pattern in such a way that variations of T_a within the limits of the main ray may be neglected, we shall have for antenna temperature the expression

$$n_A(\theta) = T_a(\theta) \frac{\int\limits_{\Omega_{r\pi}} F_0 d\Omega}{\int\limits_{4\pi} F_0 d\Omega} \eta. \tag{6}$$

At small angles to the horizon the antenna pattern F is formed under the influence of differential refraction, which leads, as is well known, to erfraction attenuation of antenna amplification. In this case we shall represent the temperature of the antenna in the form

$$n_A(\theta) = T_a(\theta) \frac{\int\limits_{\Omega_{r\pi}} F d\Omega}{\int\limits_{4\pi} F d\Omega} \eta = T_a(\theta) \frac{\int\limits_{\Omega_{r\pi}} F_0 d\Omega}{\int\limits_{4\pi} F_0 d\Omega} \eta \times \frac{\int\limits_{4\pi} F_0 d\Omega \Big/ \int\limits_{4\pi} F d\Omega}{\int\limits_{\Omega_{r\pi}} F_0 d\Omega \Big/ \int\limits_{\Omega_{r\pi}} F d\Omega} = T_a(\theta) \frac{\int\limits_{\Omega_{r\pi}} F_0 d\Omega}{\int\limits_{4\pi} F_0 d\Omega} \eta \frac{\xi_{r\pi}}{\xi}.$$

[where $\Omega_{r\pi}$ refers to the main ray]. Inasmuch as the quantity $4\pi \Big/ \int\limits_{4\pi} F d\Omega$ is the antenna amplification, the ratio

$$\xi = \int\limits_{4\pi} F d\Omega \Big/ \int\limits_{4\pi} F_0 d\Omega$$

characterizes the refraction attenuation of the amplification, and the ratio

$$\xi_{r\pi} = \int\limits_{\Omega_{r\pi}} F d\Omega \Big/ \int\limits_{\Omega_{r\pi}} F_0 d\Omega$$

— the refraction attenuation along the main ray.

When measuring the radioemission of the atmosphere, it is most practical to calibrate the received intensity by radioemission of the hill concealing the main lobe of the radiation pattern. Usually the antenna is disposed at distances of the order of several D^2/λ from the hill. At such distances, the inhomogeneity of the atmosphere may be neglected (on account of Earth's sphericity) along the ray, and, consequently, in the direction of the hill the antenna radiation pattern may be considered as formed in a uniform medium. If radioemission of the hill has the character of emission of an absolutely black body at temperature T_0, the antenna temperature at reception of hill's radioemission will be

$$n_{\text{г}} = T_0 \frac{\int\limits_{\Omega_{\text{гл}}} F_0 d\Omega}{\int\limits_{4\pi} F_0 d\Omega} \eta. \tag{7}$$

From the relations (6) and (7) we shall find the brightness temperature of the atmosphere in the direction θ:

$$T_a(\theta) = \frac{n_A(0)}{n_{\text{г}}} T_0 \frac{\xi}{\xi_{\text{гл}}}. \tag{8}$$

The errors in the determination of $T_a(\theta)$ at sucha calibration method constitute ±10%. The atmosphere's redioemission was experimentally investigated during the night, in clear weather, at angles from 0 to 10° above horizon, with wavelength λ = 30 cm and with an antenna having a 42' width of radiation pattern by half-power level.

In order to diminish the influence of the Earth at low angles, the distributions were taken down in the direction of horizon lowering. The curve, averaged by numerous distributions, is plotted by dots in Fig.2 and it constitutes a value

$$T_a(\theta) \frac{\xi_{\text{гл}}}{\xi}.$$

It may be seen from Fig.2 that the computed points coincide with the curve obtained and, consequently also with the ratio $\xi_{\text{гл}}/\xi$, which may also be represented in the form

$$\frac{\xi_{\text{гл}}}{\xi} = \frac{\int\limits_{\Omega_{\text{гл}}} F d\Omega}{\int\limits_{4\pi} F d\Omega} \frac{\int\limits_{4\pi} F_0 d\Omega}{\int\limits_{\Omega_{\text{гл}}} F_0 d\Omega} = \frac{(1-\beta)_{\text{реф}}}{1-\beta} = 1. \tag{9}$$

Inasmuch as the quantity

$$\int\limits_{\Omega_{\text{гл}}} F_0 d\Omega \Big/ \int\limits_{4\pi} F_0 d\Omega = 1 - \beta$$

characterizes the fraction of power entering into hhe main ray of radiation pattern, it follows from the equality to unity of the ratio $1 - \beta$ in uniform medium lo $(1 - \beta)_{\text{реф}}$ at refraction attenuation along the main ray, that the lateral antenna scattering does not rise.

The coincidence of the computed and the experimental curves for atmosphere's radioemission temperature allows us to derive the conclusion that the effective lengths $l_{эф}$, computed and compiled in Table 1, are correct, which is in its turn an additional corroboration of the validity of the value of the coefficient of absorption and its effective height, determined in [3].

The experimental determination of the value of refraction attenuation of antenna amplification may be obtained during measurements of fluxes of discrete point sources at low and high altitudes. If the antenna radiation pattern is normalized for the unity, the antenna temperature during reception of a point source at the altitude θ is

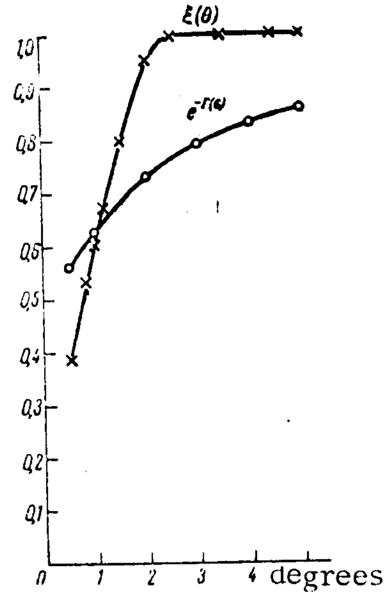

Fig.3

$$n_н(\theta) = \frac{\lambda^2 S_н e^{-\varkappa_0 l_{эф}(\theta)}}{2k \int\limits_{4\pi} F d\Omega}, \tag{10}$$

where $S_н$ is the flux from the discrete source in the wavelength λ. From the antenna temperature ratios, measured when accompanying the source from its rise to great altitudes θ_0, we shall find the value of amplification's refraction attenuation :

$$\xi = \frac{n_н(\theta)}{n_н(\theta_0)} \frac{e^{-\varkappa_0 l_{эф}(\theta_0)}}{e^{-\varkappa_0 l_{эф}(\theta)}}, \tag{11}$$

where the radiation attenuation on account of absorption in the atmosphere $e^{-\varkappa_0 l_{эф}(\theta)}$ is easily computed with the aid of Tables 1 and 2. For altitudes from 5 to 0°30' the behaviour of $e^{-\Gamma(\theta)}$ is illustrated by the lower curve in Fig.3.

The refraction attenuation of antenna amplification was experimentally investigated in the wavelength λ = 30 cm at rising and setting of the discrete source Cygnus-A. The antenna temperatures for this source, referred to antenna temperature for the 5° height, are plotted in Fig.4. The curve obtained characterizes the total radiation attenuation during transit through the atmosphere. Eliminating from it with the aid of (11) the radiation attenuation on account of absorption in the atmosphere, we shall obtain the dependence of the magnitude of antenna amplification's refraction attenuation on the altitude above horizon represented by the upper curve in Fig.3. As may be seen from the diagram, the refraction attenuation takes place at angles <2.5° above horizon and rises nearly linearly as the altitude decreases; thus, for θ = 0°30' the amplification drops already by 60%. The accounting for this circumstance is of particular importance when estimating the fluxes from discrete sources visible at low altitudes.

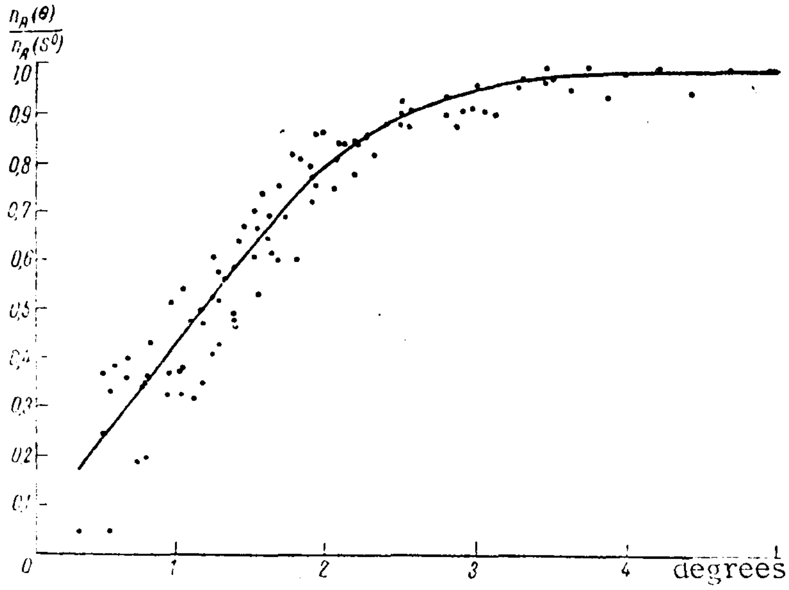

Fig.4

When receiving extended discrete sources, the refraction attenuation decreases by the quantity $\xi_{\text{п}}$, where $\xi_{\text{п}}$ is antenna amplification's refraction attenuation in the solid angle of the discrete source, and also when its angular dimensions become of the order of the width of antenna radiation pattern at the level of a few percent in power ; then $\xi/\xi_{\text{гл}} = 1$, as this took place when receiving the atmosphere's radioemission.

***** THE END *****

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